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A New Anatomic Score for Prognosis After Cardiac Catheterization in Patients With Previous Bypass Surgery

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OBJECTIVES The purpose of this study was to determine the value of a new anatomic score for prognosis after diagnostic catheterization in patients with previous coronary artery bypass grafting (CABG).

BACKGROUND Previous CABG patients comprise a growing proportion of patients with coronary artery disease (CAD). Whereas prognostic scores are available to adjust for native CAD, there are no comparable scores for patients with previous CABG.

METHODS We studied 3,178 previous CABG patients (2,729 in a training set) who underwent cardiac catheterization. With a Cox model to develop relative weights in the training set, we created a graft index that adjusted native anatomy for territories with grafts free of significant (≥75%) stenoses. Scaling the regression coefficients by the maximum coefficient created an index ranging from 0 to 100, where 100 was three-vessel CAD with no patent grafts.

RESULTS The graft index was significantly associated with all-cause death (chi-square = 121.9, $p < 0.001$). In combined models, the index was more strongly associated with all-cause death than either number of diseased vessels (chi-square = 68.0 and 1.7, respectively) or the Duke CAD index (chi-square = 54.3 and 9.5, respectively). In models for death using an independent validation set, the index was also associated more strongly than either native disease descriptors. In a model including other clinical variables, the graft index remained significantly associated with all-cause death (chi-square = 40.1, $p < 0.001$).

CONCLUSIONS For previous CABG patients, the Duke graft index was significantly more associated with prognosis than native anatomy alone and quantifies the effect of patent grafts on survival. This tool has the potential to help determine prognosis and inform the referral of post-CABG patients to repeat revascularization procedures. (J Am Coll Cardiol 2005;46:1684–92)

With more than 500,000 procedures performed annually, coronary artery bypass grafting (CABG) is now the most common major operation in the U.S. (1). Unfortunately, CABG does not permanently solve the problem of coronary artery disease (CAD). Managing patients with previous CABG and recurrent symptoms poses a growing clinical challenge. Acute coronary syndromes, percutaneous revascularization procedures, and redo surgery all have higher complication rates for patients who have previously undergone CABG (2–9).

These sobering statistics underscore the need for accurate and rational treatment selection for these patients when they return to the health care setting years after CABG with recurrent symptoms. Decisions about which patients might benefit the most from further revascularization procedures can be made in an informed way only if clinicians have adequate risk stratification tools.

Although several angiographic schemes have been developed to describe native coronary anatomy, we are unaware of any published efforts to stratify patients with previous CABG by angiography accounting for graft patency. Given the significant impact of coronary anatomy on prognosis, an improved anatomic scheme that accounts for graft patency would be an important initial step in developing comprehensive risk-adjustment tools for such patients. Moreover, relating coronary anatomy to survival with medical therapy alone would be a critical prelude to understanding the benefits of further revascularization. In this study, we developed and validated a new experience-based anatomic score for prognosis in patients with previous CABG.

METHODS

Patient population. With the Duke Cardiovascular Disease Databank, we identified patients with at least one previous CABG (i.e., any patient with a previous CABG was eligible for inclusion) who underwent diagnostic cardiac catheterization between January 1, 1986, and December 31, 2001. After their index catheterization, patients were followed at six months and annually for mortality status by telephone contact, mailed questionnaire, and National

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Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CAD = coronary artery disease
IMA = internal mammary artery
LAD = left anterior descending coronary artery
MI = myocardial infarction
RCA = right coronary artery
SVG = saphenous vein graft

Death Index search. The methods used by the Cardiovascular Databank have been described previously (10,11).

We excluded patients with previous valve surgery, moderate or severe valve disease, or congenital heart disease. During the study period, 55,602 diagnostic catheterizations were performed on patients without these exclusions. Of these, there were 7,031 catheterization procedures in 4,330 unique patients who had previously undergone CABG. We included only first catheterizations. Data from second or subsequent catheterizations were excluded. In these 4,330 patients, we excluded 497 patients with sequential (jump) or Y grafts, because these grafts frequently spanned two anatomic territories and were, therefore, difficult to credit in our scheme (see following description). We further excluded 655 patients with incomplete graft data. There were 3,178 patients in the final analysis set. Before analysis, the population was divided by random assignment into a 2,729-patient training set and a 449-patient validation set.

Development. Our objective was the development of an anatomic score for prognosis in patients with previous CABG. We used the clinical outcomes of the population to derive the index values (an "experience-based" approach), creating a score for relating the different classes to one another (12). An alternative ("rule-based") approach (examples for native coronary anatomy include Gensini and Green Lane Hospital scores) would be to specify a set of rules that describe the hierarchy. Because a rule-based approach does not lend itself to "scaled" measurements of how different classes relate to one another, even though the classes might be correctly ranked, we chose to create the graft index with an experience-based method.

We developed the graft index in the training set using five steps. First, we grouped training-set patients into disease categories according to the number of diseased native coronary territories (one, two, or three). Patients with left main disease were initially considered to have at least two diseased territories (three, if there was also significant right coronary artery [RCA] disease). We then subdivided these groups into subcategories, using the number of protected territories. Each territory with native disease was considered protected if it had at least one patent, non-significantly diseased (<75% stenosis) graft. No credit was given for additional grafts to a protected territory. Territories without significant disease could not be considered protected. Therefore, patients with one-vessel native disease could have either zero or one protected territory (making two subcategories). Patients with two-vessel native disease could have zero, one, or two protected territories (making three subcategories). Patients with three-vessel native disease could have zero, one, two, or three protected territories (making four subcategories).

These categories were entered as individual variables into a Cox proportional hazards regression model for mortality to determine their relative weights. Time zero for all models was date of diagnostic catheterization. Index values for each category were obtained by dividing each regression coefficient by the largest regression coefficient (for three-vessel native disease with no protected territories), multiplying by 100, and rounding to the nearest integer. Because of the close approximation in their index values, the lowest two categories (one-vessel disease with no protected territories and one-vessel disease with one protected territory) were combined for further analyses. The proportional hazards assumption was checked with the combination of an interaction test with time and stratified Kaplan-Meier curves. There were no obvious violations of the assumption.

To further quantify the independent contributions of significant left main coronary disease and in situ (i.e., not "free") internal mammary artery (IMA) grafts in the Cox model, we included separate indicator variables for each. We did not have enough patients in our dataset with free IMA grafts to examine their utility separately. For both left main disease and IMA grafts, this produced parameter estimates that could be scaled as an adjustment factor to the graft index.

A series of Cox models tested the association of this index to outcome relative to two other CAD descriptors: number of diseased native vessels and the Duke CAD index. The derivation of the Duke CAD index has been described previously (13). The primary end point for our analysis was all-cause death. Patients were censored at the time of cardiac revascularization procedures.

With the training set, Cox model sensitivity analyses were performed to test the index model assumptions. The definition of graft patency was varied (<50%, <95%, <100% stenosis). The independent effect of grafting specific territories (left anterior descending coronary artery [LAD], RCA, and left circumflex coronary artery) was assessed by specifying indicator variables for each territory.

Validation. Because models evaluated in their derivation population tend to provide an overly optimistic assessment of their performance, after all assumption testing and sensitivity analyses were completed, the index was validated with two methods. First, we examined the prognostic value of the index in a series of Cox models using the patient set (validation set) not previously used to fit the model (split-sample validation). This validation technique has been used previously at our institution (14,15). Second, the index was validated internally with bootstrap estimation of the entire patient sample.

Finally, after all other analyses were completed, to ensure that the weights of the index were based on all the available prognostic information, the index, left main, and IMA

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correction factors were recalculated using all 3,178 patients. This recalculated index was subsequently included in a series of Cox models with other clinical variables to assess its added prognostic value for both all-cause death (censoring on revascularization) and the combined end point of death or revascularization. Analyses were performed with SAS statistical software (SAS Institute, Cary, North Carolina).

RESULTS

The baseline characteristics of the 3,178 patients in the analysis set are shown in Table 1. The majority were men (71%) and Caucasian (86%). The median age was 63 years. In this post-CABG population, 66% had three-vessel native coronary disease and 61% had a history of myocardial infarction (MI). The majority of patients (98%) had a history of angina, and most (80%) had experienced angina within six weeks of catheterization. Left IMA grafts were present in 46%, and right IMA grafts were present in 4%. Patients underwent cardiac catheterization a mean of 4.1 years (median 2.8 years) after CABG (Table 2).

During the follow-up period (1986 to 2002), 601 patients died (529 in the training set and 72 in the validation set). Within 30 days of diagnostic catheterization, 954 patients underwent percutaneous coronary intervention and 192 patients underwent redo CABG. Patients selected for redo CABG were more likely to have three-vessel disease (78% compared with 66% in the complete cohort) and were less likely to have an intact left IMA graft (12% compared with 31% among patients not receiving redo CABG).

The initial graft index categories with corresponding index values (0 to 100), hazard ratios, and survival estimates are shown in Table 3. Column one displays the index values calculated with only the training sample patients. As expected, patients with three-vessel disease and no protected territories (no patent grafts) had the worst prognosis and the highest index value, 100. Patients with one-vessel disease (with or without a protected territory) had the best prognosis and the lowest index value, 34. Kaplan-Meier curves for patients with one- or two-vessel native disease are shown in Figure 1. Kaplan-Meier curves for patients with three-vessel disease are shown in Figure 2. These survival curves demonstrate how accounting for graft patency identifies populations with different mortality risk within each category of native disease.

Table 1. Baseline Characteristics

Characteristic (%)	All Patients n = 3,178
Age (yrs), median (25th, 75th)	63 (55, 70)
Caucasian	86.1
Male	71.3
History of PCI	24.4
History of stent	6.5
Hypertension	67.3
Carotid bruits	18.3
Charlson index >1	24.1
CHF	30.3
Class IV CHF	5.5
History of angina	97.7
Angina in previous 6 weeks	79.8
Diabetes	32.3
Cerebrovascular disease	16.7
COPD	8.1
Peripheral vascular disease	20.5
Previous myocardial infarction	60.6
Hyperlipidemia	68.0
History of smoking	70.8
Symptom duration (months), median (25th, 75th)	78 (28, 139)
Episodes of pain per week, median (25th, 75th)	4 (2, 7)
Time since prior CABG (yrs), median (25th, 75th)	2.8 (0.7, 6.4)

CABG = coronary artery bypass graft; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; PCI = percutaneous coronary intervention.

Table 2. Baseline Catheterization Data

Characteristic (%)	All Patients n = 3,178
No. of diseased vessels	
0 (no significant disease)	1.2
1	9.3
2	23.6
3	65.9
Significant left main disease	13.9
Grafts to LAD	86.8
Grafts to right coronary	72.1
Grafts to left circumflex	75.2
Significant disease in LAD graft	32.2
Significant disease in RCA graft	43.9
Significant disease in LCX graft	46.2
Total occlusion in LAD graft	20.0
Total occlusion in RCA graft	31.5
Total occlusion in LCX graft	29.3
Left internal mammary artery	46.0
Right internal mammary artery	3.7
Ejection fraction, median (25th, 75th)	53 (42, 62)
Mitral insufficiency 1+/2+	25.1

LAD = left anterior descending artery; LCX = left circumflex coronary artery; RCA = right coronary artery.

IMA and left main effects. In Cox models including the base version of the graft index, presence of a patent IMA (Wald chi-square = 18.1, p = 0.0001) and left main disease (Wald chi-square = 15.4, p = 0.0001) were each significantly associated with survival. For this end point, the graft index adjustment for a patent IMA compared with a patent saphenous vein graft (SVG) was −24, and the adjustment for significant left main disease was +28 (Table 4). The IMA correction factor is substantial enough that a patent IMA confers as much or even more survival benefit than two patent SVGs at each level of native disease (Table 4). The benefit of an IMA graft is demonstrated in the better survival for patients with two-vessel native disease with one territory protected by an IMA graft and one territory protected by an SVG, compared with patients with similar native disease and either both territories protected by SVGs or no patent grafts (Fig. 3). Similarly, the left main correction (in addition to the base assumption of assuming left main disease was equivalent to two-vessel disease) is even larger in effect. Table 4 shows the index values

Table 3. Graft Index for All-Cause Death Without Left Main or IMA Adjustment

Index Value Training Set Patients Only	Patient Category	Hazard Ratio (95% CI)	3-Yr Survival	5-Yr Survival	7-Yr Survival
0	No significant disease	NA	100	95.7	95.7
34	1-vessel with ≤1 protected territory	1.78 (0.64–4.95)	90.9	86.2	81.5
54	2-vessel with 2 protected territories	2.46 (0.90–6.69)	90.6	83.7	78.4
64	3-vessel with 3 protected territories	2.90 (1.07–7.86)	88.4	83.7	72.4
68	2-vessel with 1 protected territory	3.35 (1.22–9.24)	86.0	77.7	67.2
78	2-vessel with 0 protected territory	3.70 (1.26–10.9)	80.2	78.1	72.9
81	3-vessel with 2 protected territories	4.28 (1.58–11.6)	80.8	70.4	60.1
88	3-vessel with 1 protected territory	5.16 (1.90–14.0)	81.0	63.4	51.5
100	3-vessel with 0 protected territory	6.61 (2.43–18.0)	75.1	60.7	46.8

Survival data calculated from all patients (training and validation sets).
CI = confidence interval; IMA = internal mammary artery.

recalculated with all patients (training and validation samples).

Training set models. In the training set, the graft index was more strongly associated with prognosis than either number of diseased vessels (incremental chi-square = 53.6, $p < 0.001$) or a more sophisticated native disease descriptor, the Duke CAD index (incremental chi-square = 40.2, $p < 0.001$) (Table 5). In combination with number of diseased vessels, only the graft index remained significantly associated with death ($p = 0.0001$). The combination model that included both the Duke CAD index and the graft index had the highest model chi-square values (log-rank chi-square = 118.4) with both variables retaining prognostic importance ($p = 0.0018$ and 0.0001, respectively).

Sensitivity analyses. Varying the definition of graft patency from <50% to <100% stenosis did not substantively alter our models. The model using our preferred definition of patent, insignificantly diseased grafts (<75% stenosis) was the one with the highest association with outcome as expressed by the model chi-square values. The individual territories grafted (LAD, left circumflex coronary artery, RCA) also had little independent effect on the model. In models including the graft index and variables for patent grafts to each of the three territories (log-rank chi-square = 127.7 with 4 degrees of freedom), only the graft index (log-rank chi-square = 108.2, $p < 0.001$) was significantly associated with outcome.

Model validation: independent test set. In models generated with the validation sample, the graft index again demonstrated significant independent association with death (Table 6). Compared with a model with number of diseased vessels alone, the graft index model had larger chi-square values and an incremental chi-square = 14.3 ($p < 0.001$). In the models combining graft index with the native disease descriptors, only the graft index remained a significant independent variable.

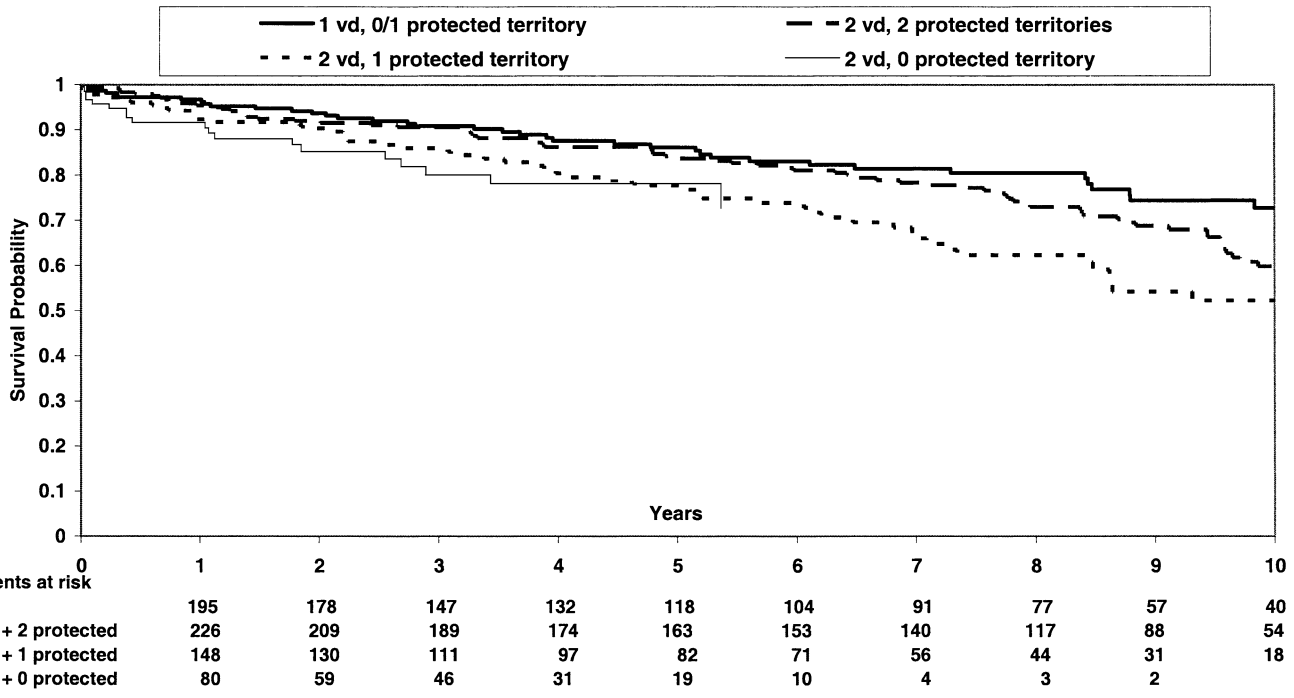

Figure 1. Survival by graft index value for patients with one- and two-vessel native disease (1 vd and 2 vd, respectively).

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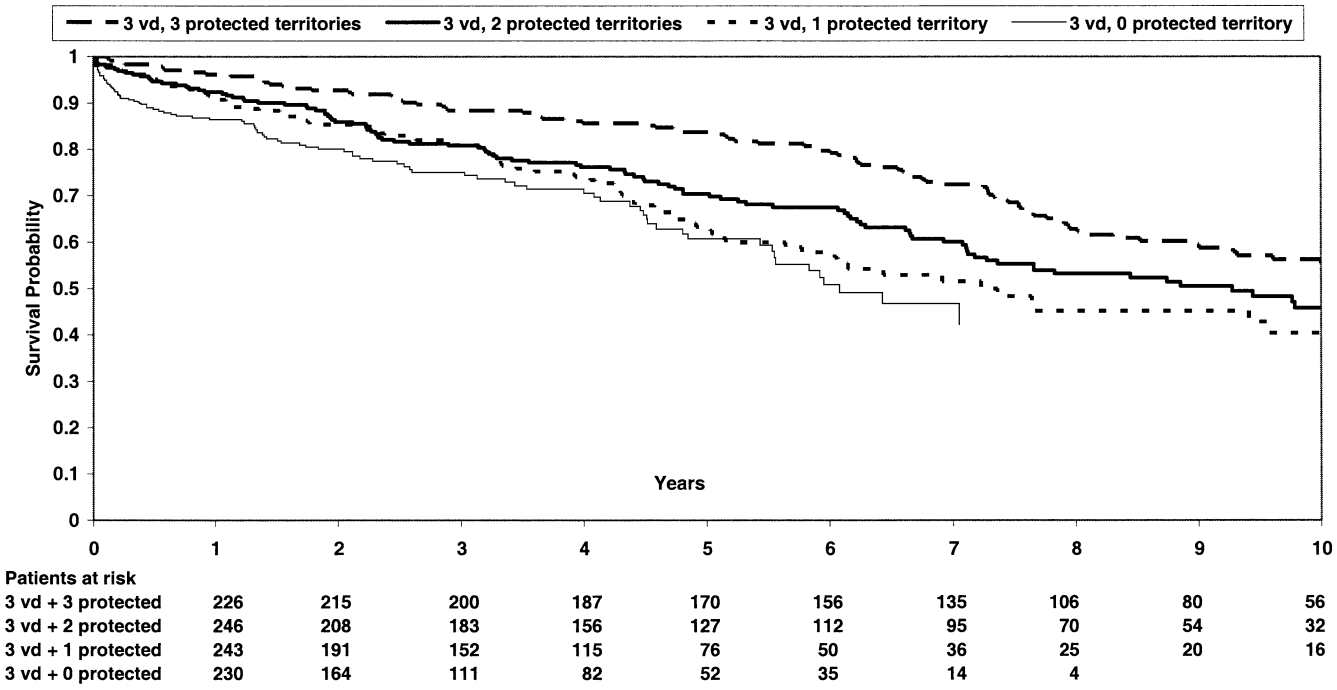

Figure 2. Survival by graft index value for patients with three-vessel native disease (3 vd).

Bootstrap validation. In addition to the split-sample validation, we also examined the graft index with bootstrap estimation. After 600 samples, the observed statistic and the bootstrap mean were the same (0.02). The confidence interval was very small (0.01 to 0.02) with a small approximate bias (0.00005). These results indicate a stable model with good validation.

Added prognostic value of the graft index. In a Cox model for all-cause death that also included age, gender, race, diabetes mellitus, hypertension, congestive heart failure, peripheral vascular disease, cerebrovascular disease, smoking, S_3 gallop, previous MI, time since CABG, and presentation with acute coronary syndrome, the graft index remained significantly associated with outcome (chi-square = 38.8, p = 0.0001). These data are shown in Table 7. In a model created by stepwise selection at the 0.05 significance level that included age, congestive heart failure, diabetes, peripheral vascular disease, time since CABG, S_3 gallop, and previous MI, the graft index retained its prognostic significance (Wald chi-square = 40.1, p = 0.0001). The only clinical variables with higher chi-square values were age and congestive heart failure. In a model combining the graft index and these clinical variables, the corrected c-index by bootstrap estimation improved from 0.63 to 0.73.

Although the graft index was designed for the end point of all-cause death, we also examined its prognostic power for the combined end point of death or revascularization. For this end point, the graft index (chi-square = 287.7, p = 0.0001) had stronger univariate association with outcome (larger chi-square) than either number of diseased vessels (chi-square = 75.1) or the Duke CAD index (chi-square = 87.9). In combined models, the graft index proved substantially more powerful than either descriptor of native disease. Combining the graft index with number of diseased vessels, the Wald chi-square values were 211.7 and 5.0, respectively. Combining the graft index with the CAD index, the chi-

Table 4. Graft Index With Left Main and Internal Mammary Adjustments Recalculated Using All Patients

Index Value	Patient Category	No Adjustments	5-Yr Survival	
			With Left Main Disease	With Intact IMA Graft
0	No significant disease	95.7	N/A	N/A
31	1-vessel with ≤1 protected territory	86.2	N/A	88.3
48	2-vessel with 2 protected territories	83.7	65.3	86.5
56	3-vessel with 3 protected territories	83.7	67.8	87.1
64	2-vessel with 1 protected territory	77.7	76.2	80.0
69	2-vessel with 0 protected territory	78.1	71.2	N/A
77	3-vessel with 2 protected territories	70.4	62.9	74.0
87	3-vessel with 1 protected territory	63.4	63.3	66.1
100	3-vessel with 0 protected territory	60.7	50.0	N/A

The index score should be adjusted by −24 points for patients with territory protected by a patent, non-significantly diseased internal mammary artery (IMA) graft and by +28 points for patients with significant left main disease.

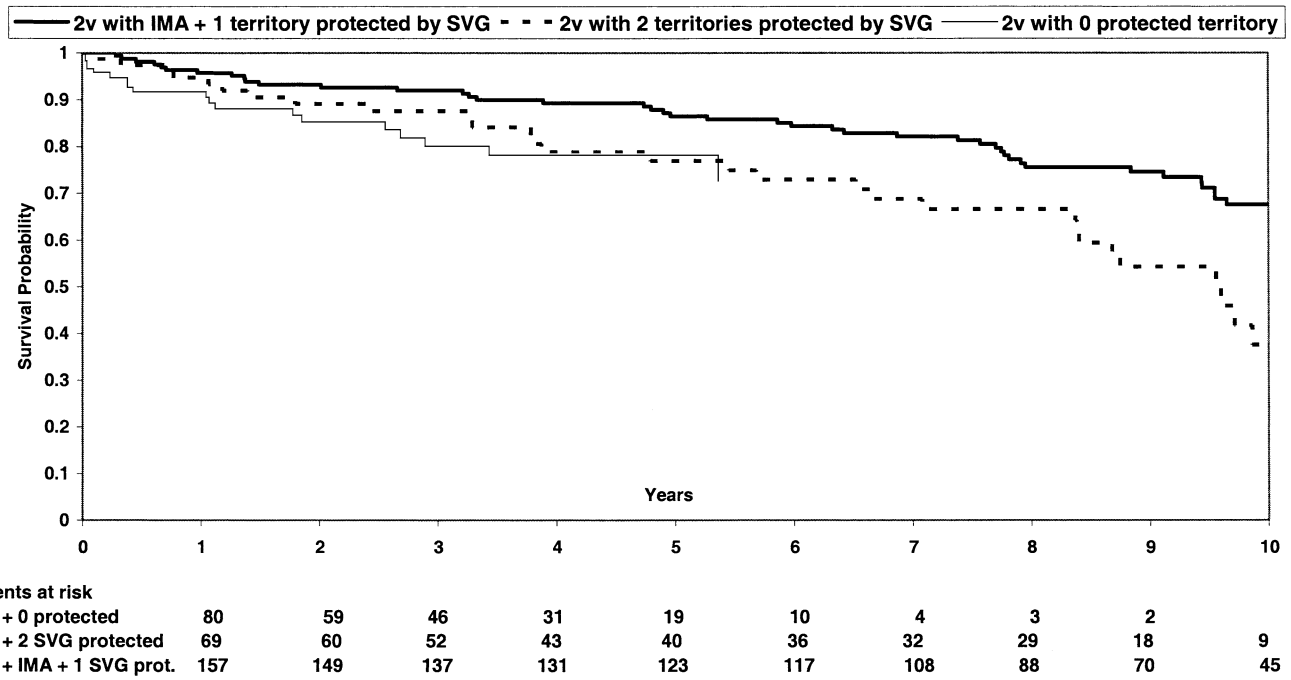

Figure 3. Survival comparison for patients with intact internal mammary artery (IMA) graft. SVG = saphenous vein graft; 2 v/vd = two-vessel disease.

square values were 195.8 and 1.3, respectively. In the multivariable models that also included age, gender, race, diabetes mellitus, hypertension, congestive heart failure, peripheral vascular disease, cerebrovascular disease, smoking, S_3 gallop, previous MI, time since CABG, and presentation with acute coronary syndrome, the graft index remained independently associated with outcome (Wald chi-square = 168.3, p = 0.0001). In the model created by stepwise selection of significant covariates that included acute coronary syndrome, time since CABG, diabetes, peripheral vascular disease, and hypertension, the graft index was the variable most strongly associated with death or revascularization (chi-square = 172.1, with all other variables chi-square <35). These data are shown in Table 8.

DISCUSSION

This study demonstrates the prognostic value of a new statistical index for estimating the survival of patients after CABG. The index has two components: one that estimates the benefit of all patent grafts in the setting of native disease (Table 3) and an additional adjustment that accounts for the benefit of IMA grafts, which is applied if an IMA graft is present (Table 4). By accounting for graft patency, models including this statistical index outperformed models using descriptors of diseased native vessels alone. Although graft anatomy is only one of several variables associated with mortality, this index significantly improves upon the current standard models that do not account for graft patency. In addition, the index retains statistical significant association with outcomes even after adjustment for native disease descriptors and other clinical variables.

Potential clinical application. The graft index estimates patient survival with medical therapy at several levels of native and graft disease. Whereas the index should prove useful to researchers investigating the post-CABG population, we hope that this tool will also be applied clinically in

Table 5. Training Set Models for All-Cause Death (n = 2,729)

Models	Wald Chi-Square	p	Model LR Chi-Square
One-variable models			
No. diseased vessels	48.7	0.0001	56.1
Graft index	106.8	0.0001	108.5
CAD index	71.4	0.0001	78.2
Combination models			
No. diseased vessels	1.2	0.2712	109.7
Graft index	53.9	0.0001	
CAD index	9.8	0.0018	118.4
Graft index	40.5	0.0001	

CAD = coronary artery disease; LR = log rank.

Table 6. Validation Set Models for All-Cause Death (n = 449)

Models	Wald Chi-Square	p	Model LR Chi-Square
One variable models			
No. diseased vessels	2.1	0.1430	2.3
Graft index	15.3	0.0001	15.5
CAD index	2.9	0.0886	3.0
Combination models			
No. diseased vessels	1.1	0.2994	16.6
Graft index	14.0	0.0002	
CAD index	0.4	0.5257	15.9
Graft index	12.6	0.0004	

Abbreviations as in Table 5.

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Table 7. Models for All-Cause Death With the Graft Index and Clinical Variables

Variables	Full Model			Model After Stepwise Selection		
	Hazard Ratio	Wald Chi-Square	p	Hazard Ratio	Wald Chi-Square	p
Age (per 10 yrs)	1.53	78.7	<0.0001	1.53	81.8	<0.0001
Gender (male)	0.91	0.9	0.3309	*	*	*
Race (white)	1.11	0.6	0.4303	*	*	*
Diabetes	1.73	36.9	<0.0001	1.73	39.2	<0.0001
Hypertension	1.18	3.0	0.0849	*	*	*
Congestive heart failure	1.84	46.8	<0.0001	1.82	45.2	<0.0001
Peripheral vascular disease	1.60	24.2	<0.0001	1.65	29.9	<0.0001
Cerebrovascular disease	1.00	<0.1	0.9776	*	*	*
Smoking	1.09	0.8	0.3747	*	*	*
Ventricular gallop	1.77	15.8	<0.0001	1.77	16.0	<0.0001
History of myocardial infarction	1.39	12.1	0.0005	1.41	13.5	0.0002
Acute coronary syndrome	1.13	2.1	0.1488	*	*	*
Time since previous CABG (yrs)	1.06	20.1	<0.0001	1.05	20.2	<0.0001
Graft index (per point)	1.01	38.8	<0.0001	1.01	40.1	<0.0001

*This variable dropped in stepwise selection model.
CABG = coronary artery bypass grafting.

guiding the management of post-CABG patients with recurrent symptoms. Like other approaches to risk stratification, the primary value of the graft index is the identification of patients that are at low risk despite their serious CAD and, therefore, might not benefit from additional revascularization. For example, patients with two-vessel CAD and territories protected by an intact IMA and SVG (graft index value = 24) have a five-year mortality of 13% (annual mortality approximately 3%). Although this would hardly be considered "low-risk" in a general population, because the observed five-year mortality rates after repeat CABG or percutaneous coronary intervention (after previous CABG) in the Emory series are 24% (annual mortality >5%) and 22% (annual mortality approximately 5%), respectively, such patients might benefit little from these procedures (6). In contrast, patients with three-vessel disease and one protected territory (graft index value = 87) have a five-year mortality of 38% (annual mortality approximately 9%) and would be likely to benefit from repeat revascularization.

Previous work. Patients who have undergone CABG exhibit different outcomes than those patients without a history of surgical revascularization. Post-CABG patients who present for acute coronary syndromes, percutaneous revascularization procedures, and redo surgery all have higher complication rates (2–9). Because the benefit of CABG intuitively derives from the patency of the bypass grafts, it is not surprising that graft atherosclerosis causing loss of patency impacts outcomes. In their angiographic and pathologic study of 50 post-CABG patients who experienced acute MI, Grines et al. (16) demonstrated that the culprit vessel was usually (76%) an SVG rather than a native vessel. Similarly, several studies have shown that progressive occlusion of grafts parallels the decline in survival in the years after CABG (3). Lytle et al. (17), examining the outcomes of 723 post-CABG patients with SVG stenosis and 573 post-CABG patients without SVG stenosis, found that patients with stenosis in vein grafts to the LAD fared worse than other patients. In contrast, Mehta et al. (18) found in a study of patients sent for redo CABG that

Table 8. Models for Death or Revascularization With the Graft Index and Clinical Variables

Variables	Full Model			Model After Stepwise Selection		
	Hazard Ratio	Wald Chi-Square	p	Hazard Ratio	Wald Chi-Square	p
Age (per 10 yrs)	1.00	≤0.1	0.8301	*	*	*
Gender (male)	1.04	0.5	0.5009	*	*	*
Race (white)	1.11	2.5	0.1137	*	*	*
Diabetes	1.17	10.5	0.0012	1.18	11.7	0.0006
Hypertension	1.12	5.6	0.0178	1.12	5.4	0.020
Congestive heart failure	0.98	0.2	0.6768	*	*	*
Peripheral vascular disease	1.13	4.8	0.0285	1.13	5.4	0.020
Cerebrovascular disease	1.06	0.9	0.3543	*	*	*
Smoking	0.99	0.1	0.7965	*	*	*
Ventricular gallop	1.01	≤0.1	0.9121	*	*	*
History of myocardial infarction	1.05	1.1	0.2906	*	*	*
Acute coronary syndrome	1.28	28.9	<0.0001	1.29	31.3	<0.0001
Time since previous CABG (yrs)	1.03	30.0	<0.0001	1.03	33.5	<0.0001
Graft index (per point)	1.01	168.3	<0.0001	1.01	172.1	<0.0001

*This variable dropped in stepwise selection model.
CABG = coronary artery bypass grafting.

clinical ischemia in undisturbed, insignificantly diseased vein grafts was uncommon.

Despite the significant influence of bypass grafts on patient outcomes, previous studies on post-CABG patients have not attempted to account for graft patency (6,7,19–22). Often, angiographic schemes to risk stratify CAD patients have excluded patients with grafts (23–25). Given the complexities of graft anatomy, the exclusion of post-CABG patients is not surprising.

Nevertheless, such an oversight comes at a price: this study demonstrates that a simple scheme accounting for graft patency adds significant prognostic information to number of diseased native vessels alone. The graft index is more powerfully associated with death than a more detailed native disease descriptor, the Duke CAD index; however, in a combined model, both the CAD index and graft index contribute significant quantities of information. This is likely because the CAD index and the graft index are assessing different patient characteristics. Specifically, whereas the CAD index identifies crucial aspects of native anatomy including stenosis severity and proximity to vessel origin, the graft index adds the prognostic information from simple graft patency.

Is it possible to incorporate these properties into a single, universal model? Attempting to account for all the permutations of graft anatomy, age, type, diameter, insertion, redundancy, and disease would not be simple. The history of anatomic scoring for native coronary disease has illustrated this problem: none of the various schemes to replace the familiar number of diseased vessels has gained widespread clinical acceptance. As information technology continues to improve, sophisticated models will doubtless become more portable, practical, and clinically applied. In the interim, we chose to narrow our efforts to examine only selected issues related to graft benefit.

Model assumptions. The importance of subclinical vein graft lesions remains controversial. Although Campos et al. reported that vein grafts with insignificant disease six years after bypass were likely to still have insignificant disease an additional five years later, Ellis et al. (26) have demonstrated that untreated graft lesions of <51% stenosis are frequently associated with subsequent adverse events (27). In their investigation of patients presenting for second redo CABG, Noyez et al. (28) reported that by the time of second redo (mean 11 years after first CABG), most of the original grafts had failed. In our sensitivity analyses, changing the patency definition to <50% stenosis decreased the prognostic power of the model (likely by introducing noise), whereas liberalizing the patency definition all the way up to any open graft failed to improve the model.

Some studies have suggested that patency rates are higher for vein grafts to the LAD compared with grafts to other territories (3,29–31). In the Lytle et al. (17) study of post-CABG patients undergoing post-operative angiography, they found that stenosis in LAD vein grafts was associated with decreased re-operation and event-free survival compared with stenosis in grafts to other vessels. Lytle et al. (17) included only patients with vein grafts (no patients with IMA grafts) and excluded all patients who underwent revascularization within one year, who were without graft stenosis or who had totally occluded grafts. Because the prognosis of MI also varies by territory, we tested for territorial differences, using indicator variables for each. In our sample, territorial differences added no prognostic information after accounting for IMA grafts. Despite this result, given the preponderance of previous data, we believe that a larger sample of patients would likely find territorial differences in survival.

Study limitations. There are several limitations to the present study. First, because the study examined symptomatic patients, our results should be generalized with caution to asymptomatic post-CABG patients; however, because very few (if any) patients should undergo catheterization without symptoms or signs of ischemia, we believe that our results should be generally applicable. Second, we only have catheterization data from one institution. Data for patients who had CABG at our institution and underwent subsequent diagnostic catheterization elsewhere was not available to us. Third, our study does not present a comprehensive risk model for patients after CABG. Whereas many variables influence survival for patients after CABG, our model attempts only to demonstrate the prognostic power of angiographic anatomy. Fourth, by censoring on revascularization procedures, our models only describe the effect of medical treatment strategies on post-CABG survival. Other non-fatal end points, such as non-fatal MI, were not considered. Fifth, we lacked sufficient patients to examine potential differences between free and in situ IMA grafts. Sixth, as with all retrospective analyses, we cannot fully correct for the influence of possible informative censoring. To partially address this issue, we have included analyses that use the combined end point of death and revascularization. As noted previously, this multivariable analysis reveals significant changes among important prognostic variables compared with the results of the model for all-cause death. Despite the shifts in clinical variables, in both models, the graft index remains significantly associated with the outcome. Finally, whereas the graft index might be useful for risk-stratification of post-CABG patients, it does not directly address the effect of revascularization strategies on baseline risk. Additional analyses to assess these effects are underway.

Conclusions. For patients with previous CABG who subsequently undergo cardiac catheterization, the Duke graft index was significantly more associated with prognosis than native coronary anatomy alone. Although it remains to be validated in another large patient population, this tool has the potential both to inform the management of patients after CABG and to improve the risk adjustment of these patients in clinical studies. By demonstrating the different medical treatment prognoses for patients with previous CABG, our study provides a baseline reference for clinicians

and researchers weighing the potential benefits of additional revascularization.

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